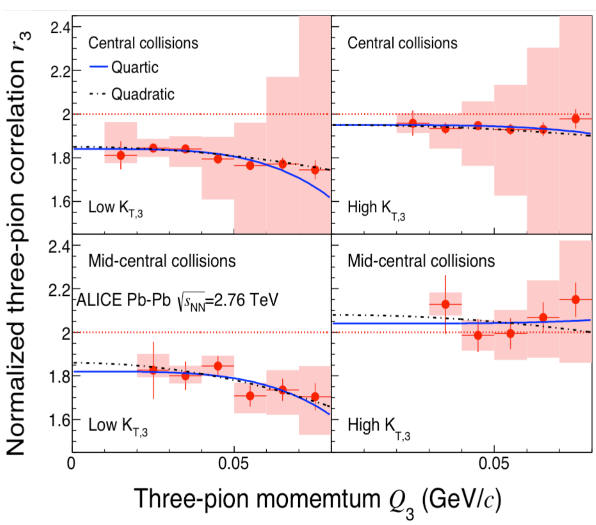
Nuclear Science Division Newsletter 2014/1

Possible formation of a Bose-Einstein condensate in heavy-ion collisions at LHC

The large initial gluon densities created in a heavy-ion collision may cause bosons to condense into a single quantum state known as a Bose-Einstein condensate. Atomic condensates have been observed before but at low temperatures. The formation and subsequent decay of a Bose-Einstein condensate may radiate pions coherently at low momentum and lead to a suppression of Bose-Einstein correlations. The ALICE collaboration at the Large Hadron Collider (LHC) has measured the Bose-Einstein correlation between two and three pions in Pb+Pb collisions at s_{NN}=(2.76 TeV)^2. Identical pion correlations at low relative momentum are dominated by Bose-Einstein statistics and Coulomb repulsion. Such correlations provide information on the space-time structure of the particle-emitting sources created in the collision and the correlation strength conveys information on the degree of quantum coherence of pion emission.



*The figure shows the ALICE measurement of r_3 versus the relative pion momentum Q_3 as obtained in central (top) and mid-central (bottom) Pb+Pb collisions for either low (left) or high (right) transverse momentum $K_{T,3}$. The chaotic upper limit is shown by the dashed red line; estimated systematic uncertainties are shown by the shaded red bands; quartic fits (solid blue lines) and quadratic fits (dashed black lines) to the experimental data are also shown. More details are given in Phys. Rev. C **89**, 024911 (2014).*

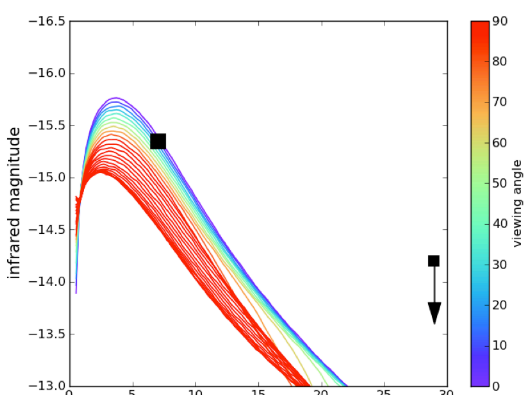
The result is expressed as the ratio of the genuine three-pion correlation strength to the triple product of pair-correlation strengths, r_3, removing the spurious contributions arising from long-lived resonances. By construction, $r_3(Q_3=0) = 2$ for the case of fully chaotic pion emission (zero coherence fraction). If the space-time pion freeze-out coordinates are momentum independent, r_3 is expected be independent of Q_3 and the coherence fraction may then be extracted for any value of Q_3. While the results for high $K_{T,3}$ are consistent with the chaotic limit (r_3=2), there is a significant suppression for low $K_{T,3}$, present for both central and mid-central collisions, suggesting a coherence fraction of 23±8%. This hints at the formation of a Bose-Einstein condensate which would present the first observation of this state of matter in a high-temperature environment. Further work is in preparation using four-pion correlations for which the expected suppression is five times larger.

New insights into *r*-process nucleosynthesis in neutron star mergers

The origin of the heaviest elements in the Universe remains one of the key open questions in nuclear astrophysics. About half of the nuclei heavier than iron are believed to form in stellar explosions via rapid neutron capture (the *r*-process) but identifying the astrophysical sites has proven difficult. Core-collapse supernovae have long been a promising candidate, but numerical simulations have (so far) failed to produce outflows with the necessary physical conditions. An appealing alternative *r*-process site is the violent merger of two neutron stars, which are thought to eject a small fraction of material, either dynamically or due to energy deposition from neutrinos or nuclear reactions; the decompression of the nuclear matter provides a robust environment for *r*-process production.

Recently, studies by faculty physicist Daniel Kasen of the NSD theory group and his graduate student Jennifer Barnes have offered new insights into *r*-process production in neutron star mergers. The two used detailed simulations to model the radioactive debris ejected in the event and calculated how beta decays and fission can power a thermal glow resembling a dim supernova. But, unlike a supernova, the unusual *r*-process composition resulted in the emission being mostly in infrared, not visible, light [1].

As luck would have it, not long after these predictions were made, a bright gamma-ray burst alerted astronomers that a neutron-star merger had occurred in the relatively nearby Universe. Motivated by the Barnes-Kasen predictions, observers pointed the Hubble Space Telescope at the event and saw a surprisingly bright infrared glow [2], similar to the predicted radioactive powered emission (Figure 2). If this identification is correct, this would be the first direct observation of freshly synthesized cosmic *r*-process nuclei. Moreover, comparison to the model allowed a yield estimate of ~0.02 solar masses, high enough that neutron-star mergers could account for the bulk of the *r*-process material in the Universe.



The radioactively powered emission from r-process nucleias calculated by Barnes & Kasen [1], color-coded by of the angle from which the neutron-star merger is viewed (0^o being face on). The squares show the detection of transient infrared emission from the Hubble Space Telescope [2].

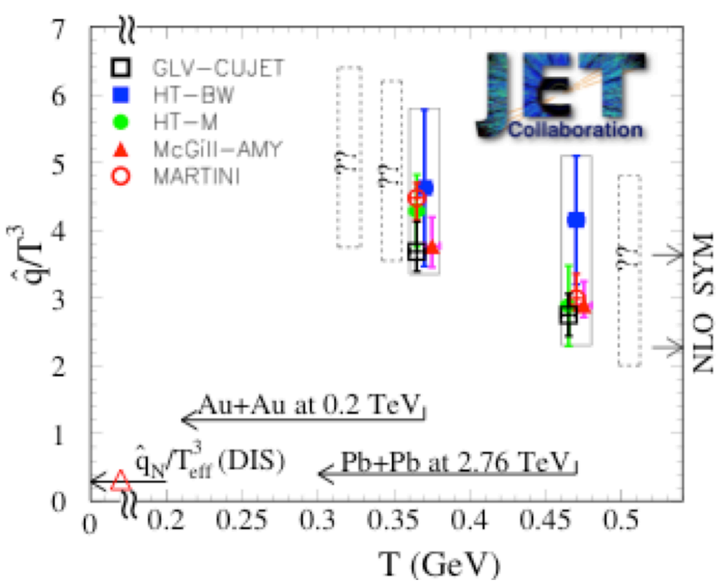
1. Barnes and Kasen, *Astroph. J., 775, 18 (2013).*
2. *Tanvir et al., Nature, 500, 547, (2013).*

Though the data on this first event are sparse and subject to other explanations, future observations of this sort hold the possibility of deriving experimental constraints on the mass and abundances of nuclei produced in NS mergers. Simulations like Kasen's are providing a link between the experimental nuclear data to be acquired at facilities like FRIB, and astronomical observations of those distant stellar explosions in which all of the heavy elements in the Universe were created.

JET Topical Collaboration extracts jet transport parameters at *RHIC* and *LHC*

Hard processes of jet production play an essential role as probes of the properties of the quark-gluon plasma (QGP) formed in high-energy nuclear collisions. Study of these energetic particles and their interaction with the medium, referred to as jet tomography, will yield critical information about the properties of the matter, complementary to that provided by soft hadrons from the bulk medium. The Topical Collaboration on Quantitative Jet and Electromagnetic Tomography (*JET*) of Extreme Phases of Matter in Heavy-ion Collisions (the *JET* Collaboration) was funded by the US Department of Energy in 2010 to address the outstanding challenges in the study of hard probes in high-energy nuclear collisions. The *JET* Collaboration has currently 12 participating institutions with LBNL as the leading institute and NSD senior scientist Xin-Nian Wang as the managing PI. A major final goal of the *JET* Collaboration is to refine the theory of jet quenching and to develop new and powerful Monte Carlo programs for phenomenological studies of experimental data and extraction of medium properties.

The jet transport parameter, defined as the average transverse momentum broadening squared per unit length of propagation, is one of the fundamental properties of the medium. Using an integrated package of jet quenching programs with different theoretical models, the *JET* Collaboration carried out the most comprehensive analyses of experimental data from both *RHIC* and *LHC* last year. Values of the jet transport parameter extracted from this study have significantly smaller theoretical uncertainties compared to similar prior studies. They are consistent with a picture of jet propagation inside QGP as described by perturbative QCD which is dramatically higher than the value in a cold nucleus. Future studies at *RHIC* beam scan energies and *LHC* top energy will provide more accurate assessment of its temperature dependence.



The jet transport parameter q-hat (scaled by the temperature T cubed) as extracted from experimental data from RHIC and LHC within various models. The value of q-hat in a cold nucleus is also indicated at very low temperature. The rectangles with question marks indicate possible values at the top LHC energy and in the region of the RHIC beam scan.

JET Collaboration also hosts annual summer schools. This year's *JET* summer school will be held on the campus of UC Davis during June 19-21, 2014. For more information about *JET* go to: http://jet.lbl.gov.

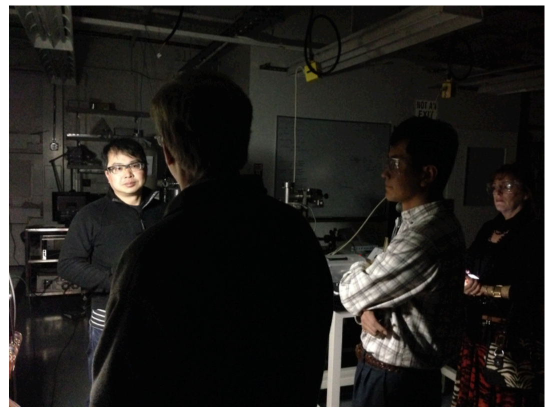
NSD Fragments

NSD takes power outage in stride

The transformer station serving building 54, 70, and 70A celebrated President's Day by a loud explosion and associated smoke. During the resulting week-long power outage, laboratory work carried out by Applied Nuclear Physics, Nuclear Chemistry, *MAJORANA*, and SNO+ were halted and the buildings were evacuated, including the Theory and RNC groups whose members were reseated in the 50 complex or worked at home.

Fortuitously, the work done last fall in preparing for a possible government shutdown helped Facilities focus on what the divisions considered critical equipment and the Department ran external power lines into the buildings to keep that equipment powered, but access to the buildings required special arrangement.

Flashing light on photon detectors



The MAJORANA lab in Bldg. 70 during the safety walk-through the second day; the illumination is from flashlights. Most of the critical equipment was on an uninterruptible power source already, limiting the damage.

Because Monday was a holiday, most people arrived at work on Tuesday unaware of the situation, including the closure of the Cafeteria. But from Wednesday on, food trucks had arrived and could provide lunch. The startup process the following Monday was well coordinated between EHS, the scientific divisions and Facilities, due in large part to the twice-daily meetings Facilities held throughout the power outage in addition to briefings of division management at the end of each day.

NSD Senior Physicist **Paul Fallon** was recently elected as Fellow by the American Physical Society for ``his use of γ-ray spectroscopic techniques to elucidate the behavior of atomic nuclei at the limits of existence, from the investigation of super-deformation at the highest angular momentum to studies of weakly bound states in light systems approaching the neutron drip-line.'' Paul was nominated by the Division of Nuclear Physics and will be receiving his certificate at the upcoming Spring Meeting in Savannah, Georgia.

NSD Director **Rod Clark** has recently started a series of brown-bag lunch-time meetings with the postdocs in the division. This is a good opportunity for the postdocs to meet one another and for the director to get impressions from the trenches and learn directly of any concerns from this key segment of the division. All NSD postdocs are encouraged to attend and share some fresh ideas.

Christopher Schmitt of Tübingen University in Germany has joined the *MAJORANA* group for a six-month research visit, funded by a DAAD PhD student fellowship; his thesis project is on the *GERDA* experiment.

This Spring, the NSD is hosting Professor **Frank Calaprice** of Princeton, a renowned experimental physicist with current interests in low-energy solar neutrinos and fundamental symmetries in nuclear β decay.

The NSD Newsletter is edited by Jørgen Randrup (JRandrup@LBL.gov) and issues are archived on the NSD home page: https://commons.lbl.gov/display/NSD/home/.